HOM Absorber Design for eRHIC ERL Cavity (Now EIC)

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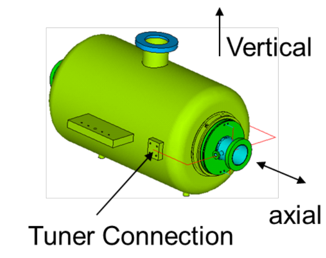
Outline

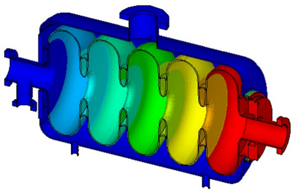
- TJS Technologies LLC (2016)
  - Engineering Services
    - MSU Michigan State University
      - FRIB ASME evaluation of 644 MHz Cavity and Tuner
    - FHI Fritz Harbor Institute - ongoing
      - Free Electron Laser Deflector Cavity
        - » RF Thermal Analysis – Design, Coupling
        - » Beam dump and beam dump window
    - JLAB - ongoing
      - SRF Cavity Cooled by Cryocoolers – Thermal Analysis
      - FPC Coupling to Locate the FPC nearer the cavity (450kW per FPC)
  - Higher Order Mode Absorber SBIR Phase I & II
    - Fabricated Prototypes
      - Waveguide planned low power RF testing
      - Beamline planned high power RF testing
  - Phase IIA
    - Tasks
    - Evaluate HOM absorber for Crab Cavity

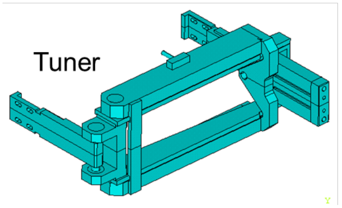
Engineering Service MSU

ASME Structural evaluation of FRIB 644 MHz Cavity and Tuner

- **General Requirements of ASME code Section VIII Division 2 – Design by Analysis**
- **Material Properties**
- **Boundary Conditions**
- **Loads to be Considered**
- **Design By Analysis 2015 Section VIII, Division 2 Part 5 of ASME Code**
  - Protection Against Plastic collapse Part 5.2
    - »Limit Load Analysis Part 5.2.3
    - »Elastic-Plastic Analysis Part 5.2.4
  - Protection Against Local failure Part 5.3
    - »Elastic Analysis 5.3.2
  - Protection against collapse From Buckling Part 5.4
    - –Bifurcation – Eigenvalue Buckling Part 5.4.1.2
  - Protection Against Failure From Cyclic Loading Part 5.5
    - –Experience with comparable equipment operating under similar conditions Part 5.5.2
    - –Ratcheting Assessment – Elastic-Plastic Stress Analysis Part 5.5.7
- **Vibration**
- **Frequency Sensitivity to Pressure**
- **Tuner Evaluation**

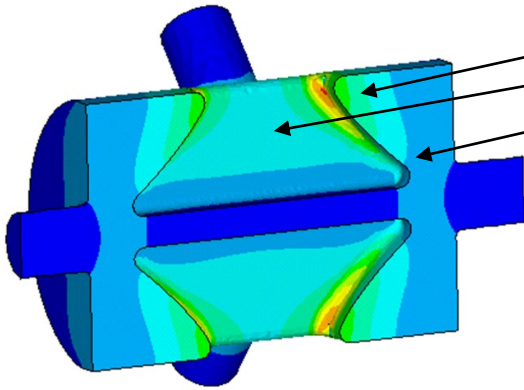






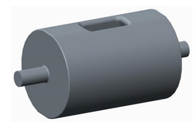
Engineering Service FHI

Develop a Beam Deflector to Provide 2 500 MHz Beams from a single 1 GHz beam for 2 Color FEL



Shape modified for 500 MHz

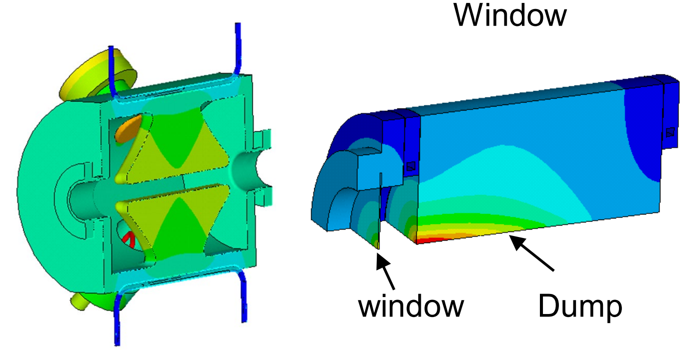
RF Analysis



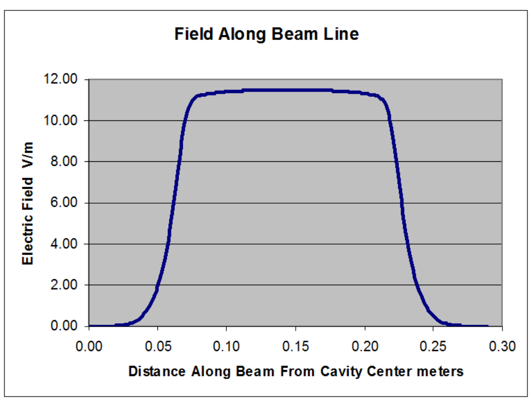
Frequency shift for manufacturing and tuning

Deflector Cavity

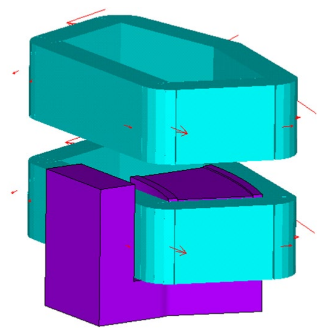
Beam Dump and Window



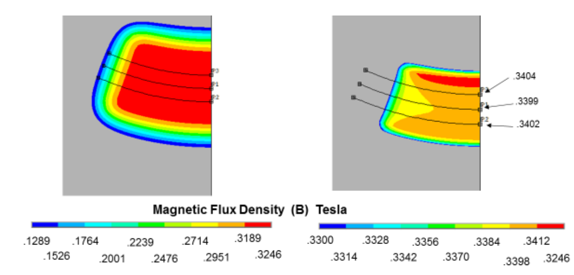
Thermal Analysis



Electric Field Along Beamline

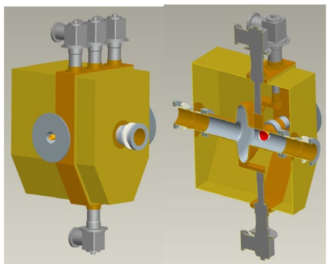


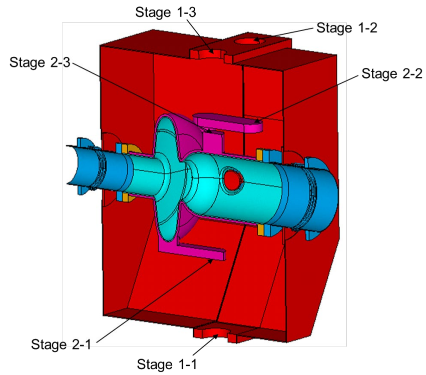
3-D Magnet calcs
Coil geometry
Specification
Field Quality

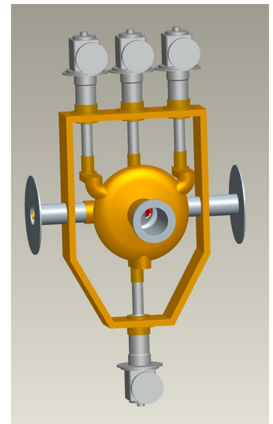


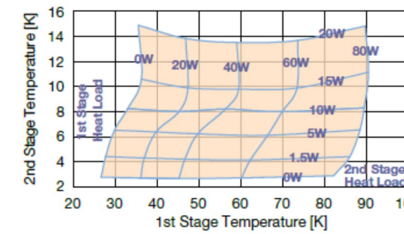
Magnet Analysis

Engineering Service JLAB

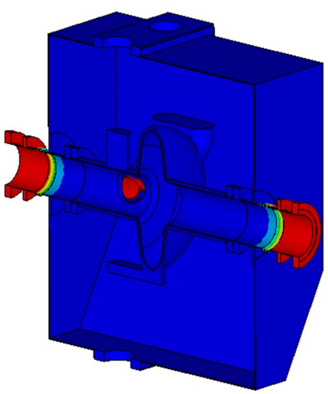




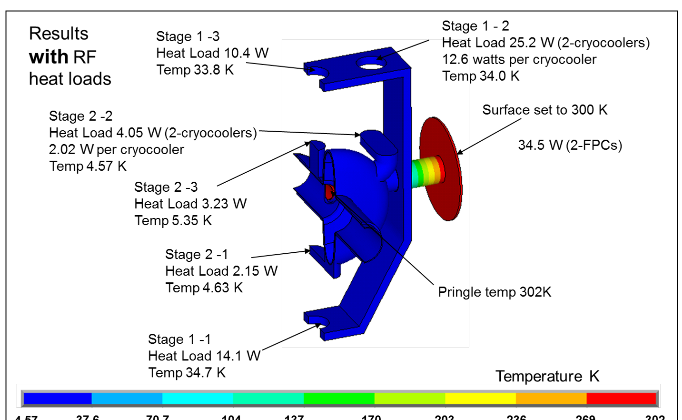


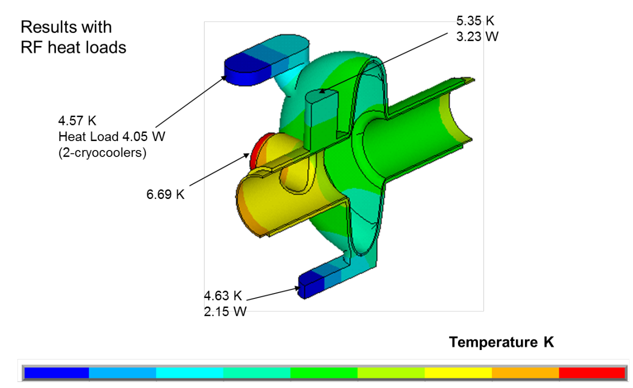


Cryocooler Capacity Map



RF and Thermal Analysis and Coupling for power couplers





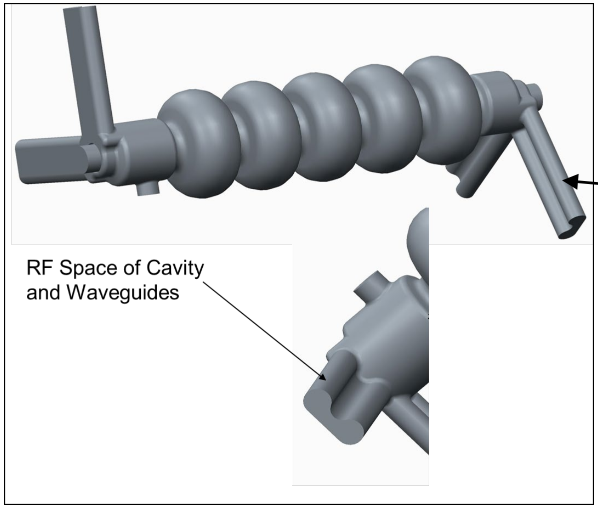
Higher Order Mode Absorber SBIR

- Motivation
  - In 2017 and 2018 BNL evaluated designs for the electron accelerator in eRHIC, now EIC, the proposed electron-ion collider
    - It included electron cooling using a multi-cell cavity with high average current and high bunch charge in CW energy recovery mode. This cavity would require a higher order mode absorber with considerable power absorption capability
    - There is also interest in Crab Cavity HOM absorbers

Higher Order Mode Absorber SBIR Tasks

- Phase I
  - Define/update HOM specifications with BNL
  - Develop the concept design of the absorber module
  - Perform RF/Thermal and Structural Analysis of the HOM module
  - Develop manufacturing plan and design for the HOM absorber module to a cost level.
- Phase II
  - Manufacture Prototypes
  - Waveguide HOM
  - Beamline HOM
- Phase II A
  - Develop low weight waveguide HOM absorber
  - RF sweep tests of waveguide prototype to determine S11 of HOMs
  - High Power absorption tests of tile/backer cores

BNL Designed Cavity and B-shaped waveguide



BNL developed a B-Shaped waveguide to suppress multi-pacting and improve impedance decreasing the number of waveguides per cavity
BNL paper SRF2017 TUPB002

Freq	Power
1.21974E+09	9.66546E+02
1.21036E+09	6.10568E+02
1.23850E+09	5.61609E+02
1.24789E+09	5.33179E+02
1.33233E+09	4.14821E+02
1.22912E+09	4.11329E+02
1.90467E+09	2.60402E+02
1.34171E+09	2.13527E+02
1.30418E+09	1.26510E+02
1.20097E+09	1.26386E+02
1.35110E+09	1.25289E+02
1.36986E+09	1.23914E+02
1.29480E+09	1.12858E+02
1.28542E+09	1.05534E+02
1.27603E+09	1.04885E+02
1.26665E+09	1.02065E+02
1.25727E+09	9.97414E+01
1.31357E+09	9.10959E+01
2.56145E+09	7.79565E+01

BNL supplied a set of HOM Freq with its associated power up to 3.1 GHz where HOM power is 1.2 e-5 W

Table to left is the power sorted by power for the first 19 HOM modes

Table supplied by BNL for freq to 3.13 GHz

For analysis HOM power is not degraded by nearby cavity mode power it is determined from beam frequency and used for design limits making the design conservative

Total Power for Freq to 3.1 GHz is 6.01 kW

Model to Determine Tile Heat Loads with curve and shortened tile length to compact geometry

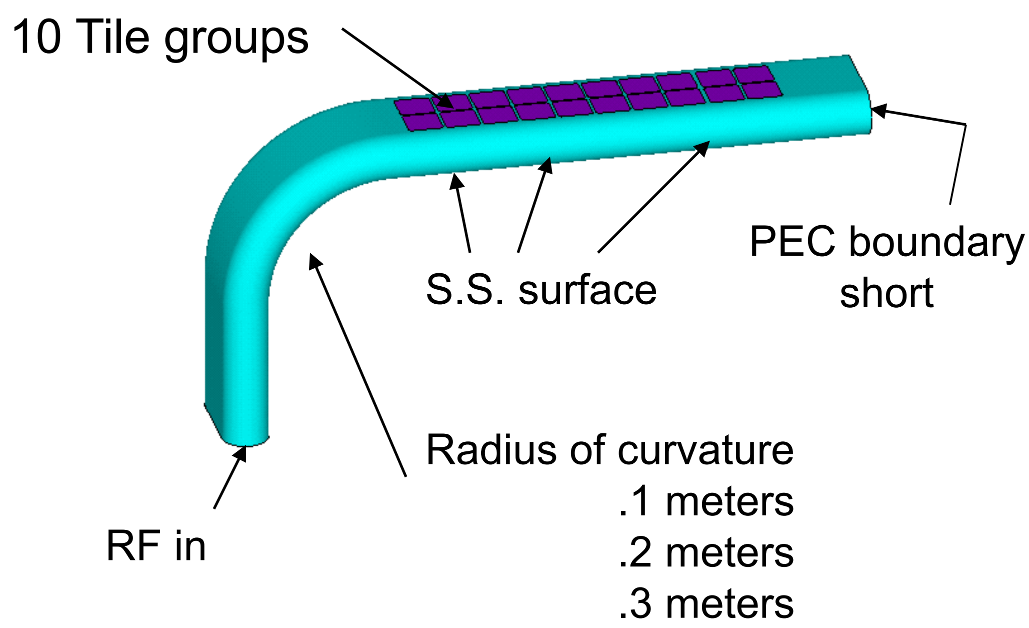
Driven Model

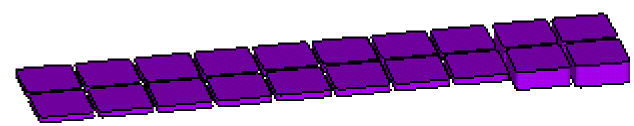
Input Excitation Port

Frequency Dependent permittivity and Loss tangent

Surface Losses assuming Stainless Steel

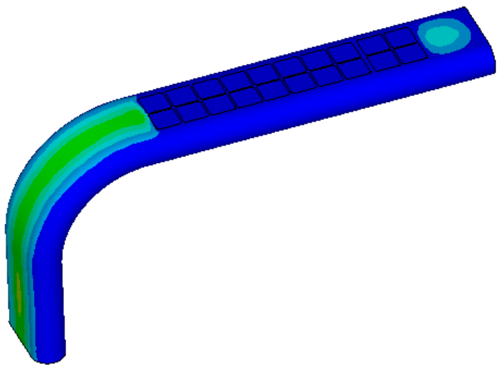
Output
S11, Power for each tile group
For each Frequency
Sum Power for each tile group over HOM frequencies





Tile groups with varying thickness
Made from SC-35, graphite loaded Silicon Carbide

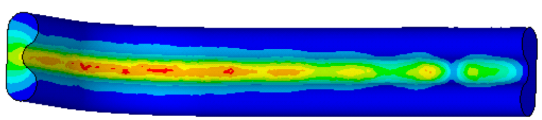
Fields at 1.2197 GHz
Curved Waveguide Radius .1 meters



Tabulate Results for all evaluated HOMs
4 HOMs per cavity

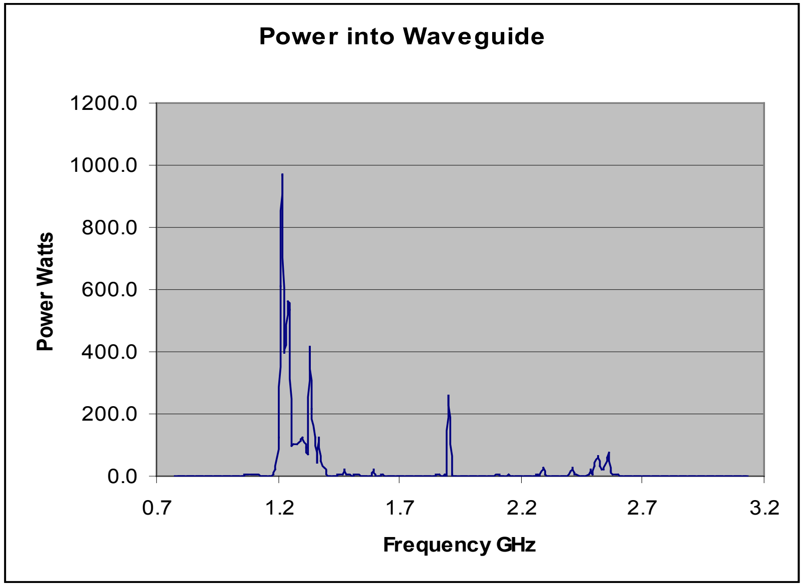
Freq	Power	S11	ReflP	Surf Loads	Id1	Id2	LD3
1.21974E+09	2.41637E+02	3.63340E-02	3.18999E-01	1.34287E+00	2.05640E+01	2.10396E+01	2.38696E+01
1.21036E+09	1.52642E+02	2.50770E-02	9.59898E-02	8.57093E-01	1.29309E+01	1.27258E+01	1.45691E+01
1.23850E+09	1.40402E+02	6.30190E-02	5.57593E-01	7.64159E-01	1.22239E+01	1.29842E+01	1.51182E+01
1.24789E+09	1.33295E+02	7.37400E-02	7.24802E-01	7.18159E-01	1.18679E+01	1.25528E+01	1.50519E+01
1.33233E+09	1.03705E+02	8.02920E-02	6.68568E-01	5.16512E-01	1.37696E+01	1.05113E+01	1.55004E+01
1.22912E+09	1.02832E+02	5.03010E-02	2.60185E-01	5.65519E-01	8.82375E+00	9.26745E+00	1.05817E+01
1.90467E+09	6.51005E+01	1.17180E-01	8.93905E-01	2.25240E-01	1.63844E+01	1.32115E+01	8.47076E+00
1.34171E+09	5.33818E+01	7.12660E-02	2.71118E-01	2.63818E-01	7.34672E+00	5.55251E+00	8.01851E+00
1.30418E+09	3.16275E+01	9.60880E-02	2.92014E-01	1.61430E-01	3.66959E+00	3.07313E+00	4.51124E+00
1.20097E+09	3.15965E+01	2.84580E-02	2.55887E-02	1.79180E-01	2.66583E+00	2.49959E+00	2.93756E+00
1.35110E+09	3.13223E+01	6.06370E-02	1.15167E-01	1.53636E-01	4.44486E+00	3.36306E+00	4.70684E+00
1.36986E+09	3.09785E+01	3.57750E-02	3.96479E-02	1.49785E-01	4.60074E+00	3.59557E+00	4.60617E+00
1.29480E+09	2.82145E+01	9.73070E-02	2.67153E-01	1.45229E-01	3.11195E+00	2.72818E+00	3.91699E+00
1.28542E+09	2.63835E+01	9.65040E-02	2.45710E-01	1.36982E-01	2.76559E+00	2.54465E+00	3.54499E+00
1.27603E+09	2.62213E+01	9.37260E-02	2.30342E-01	1.37344E-01	2.61716E+00	2.52373E+00	3.39182E+00
1.26665E+09	2.55163E+01	8.90190E-02	2.02201E-01	1.34870E-01	2.43513E+00	2.44740E+00	3.16344E+00
1.25727E+09	2.49354E+01	8.23760E-02	1.69206E-01	1.33040E-01	2.28961E+00	2.37570E+00	2.95315E+00
1.31357E+09	2.27740E+01	9.28180E-02	1.96202E-01	1.15280E-01	2.77424E+00	2.23229E+00	3.31811E+00
2.56145E+09	1.94891E+01	8.87690E-02	1.53573E-01	7.36090E-02	3.76744E+00	3.24892E+00	2.35598E+00

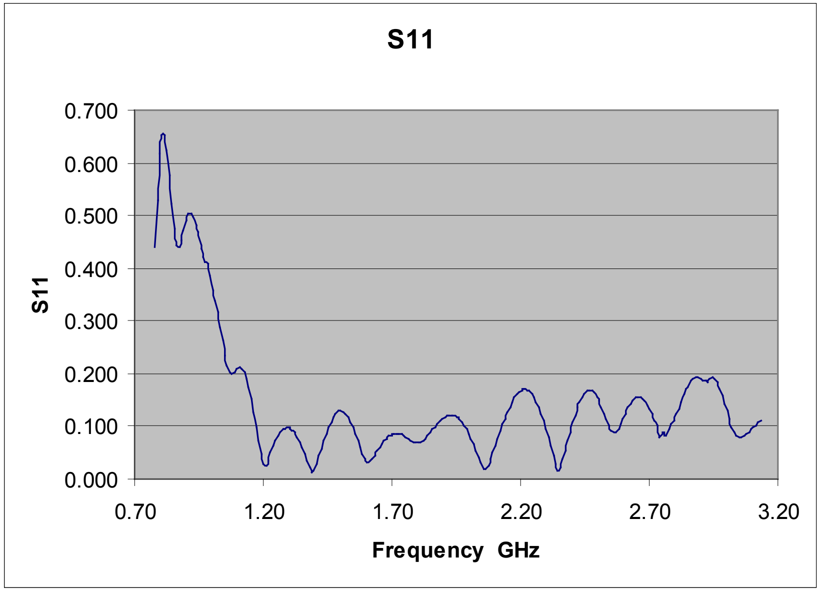
Power 241.6 Watts (966.5/4)
S11 .0363
ReflP .319 W

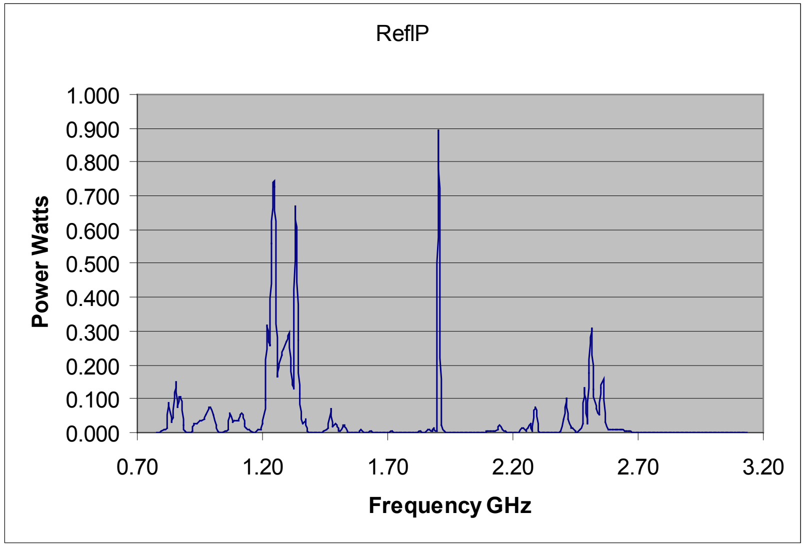


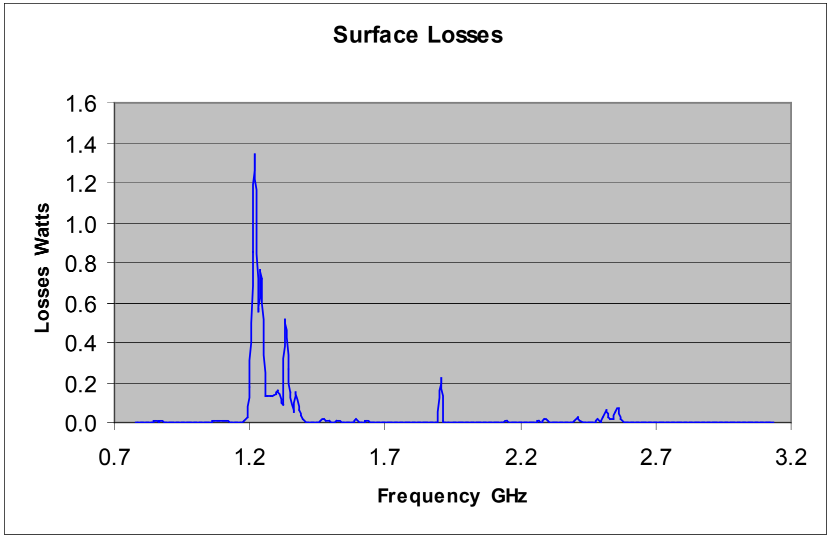
Surface Loss 1.34 W
SS surface elec cond

Power In, S11, Reflected Power, Surface Loss

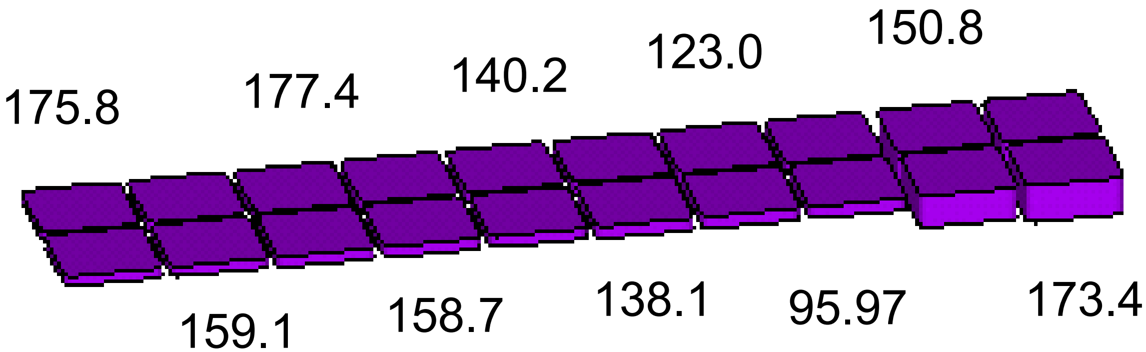








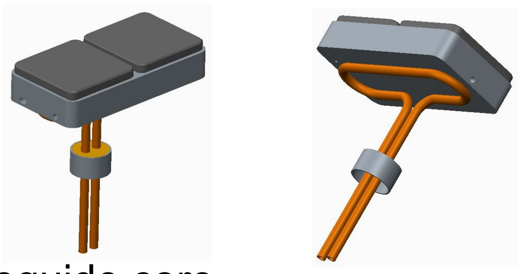
Sum of Power into Waveguide Absorber



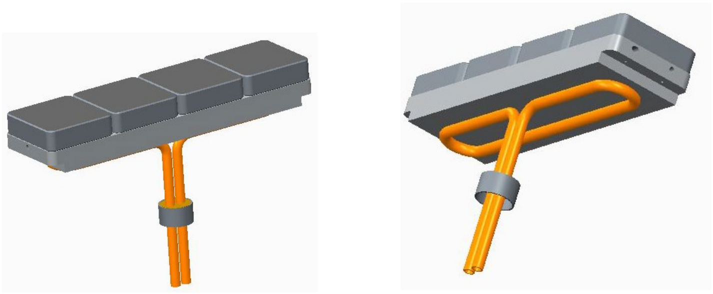
- Initial HOM absorber module geometry
  - 1492.4 W of 1501.5 W is absorbed 99.7%
  - 10 tile pairs
  - Thickness range .200” to .75”

Higher Order Mode Absorber SBIR Phase II

- Manufacture HOM Cores
  - Can be used for Waveguide or Beamline Absorber

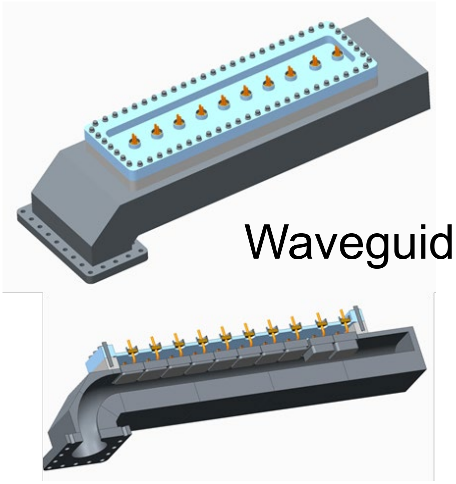


Waveguide core

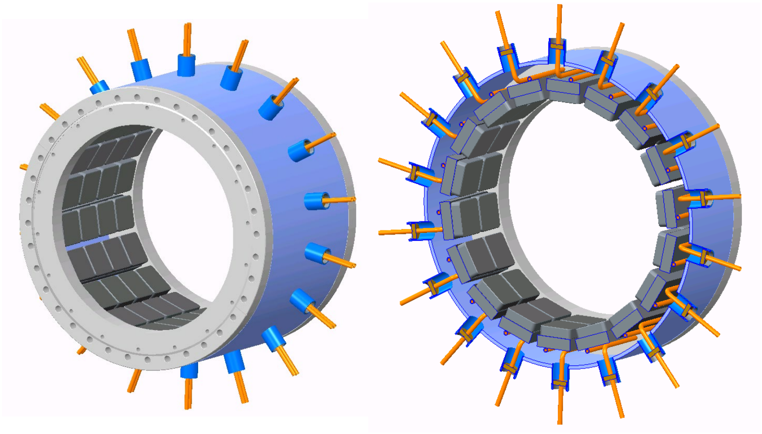


Beamline core

- Manufacture Housing and Assemble Core and Housing

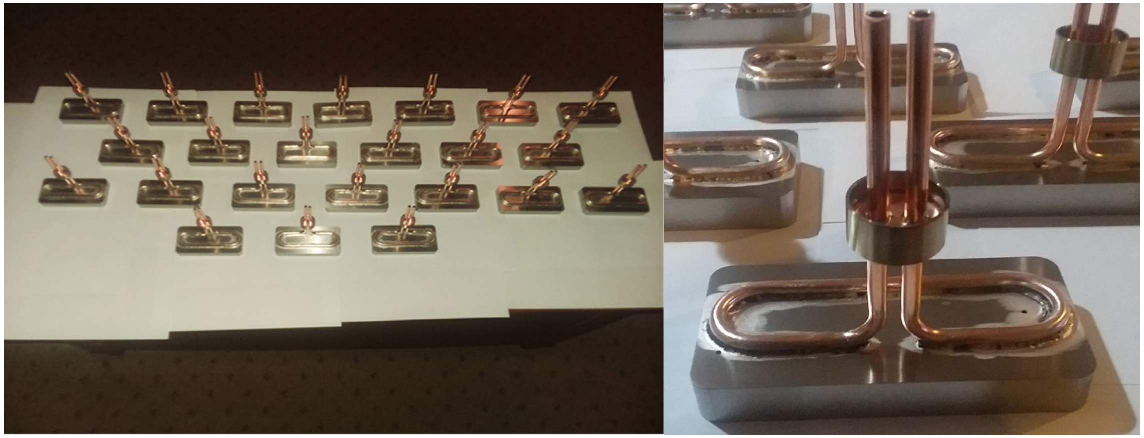


Waveguide HOM



Beamline HOM

Initial Braze Step in Fabrication of Cores

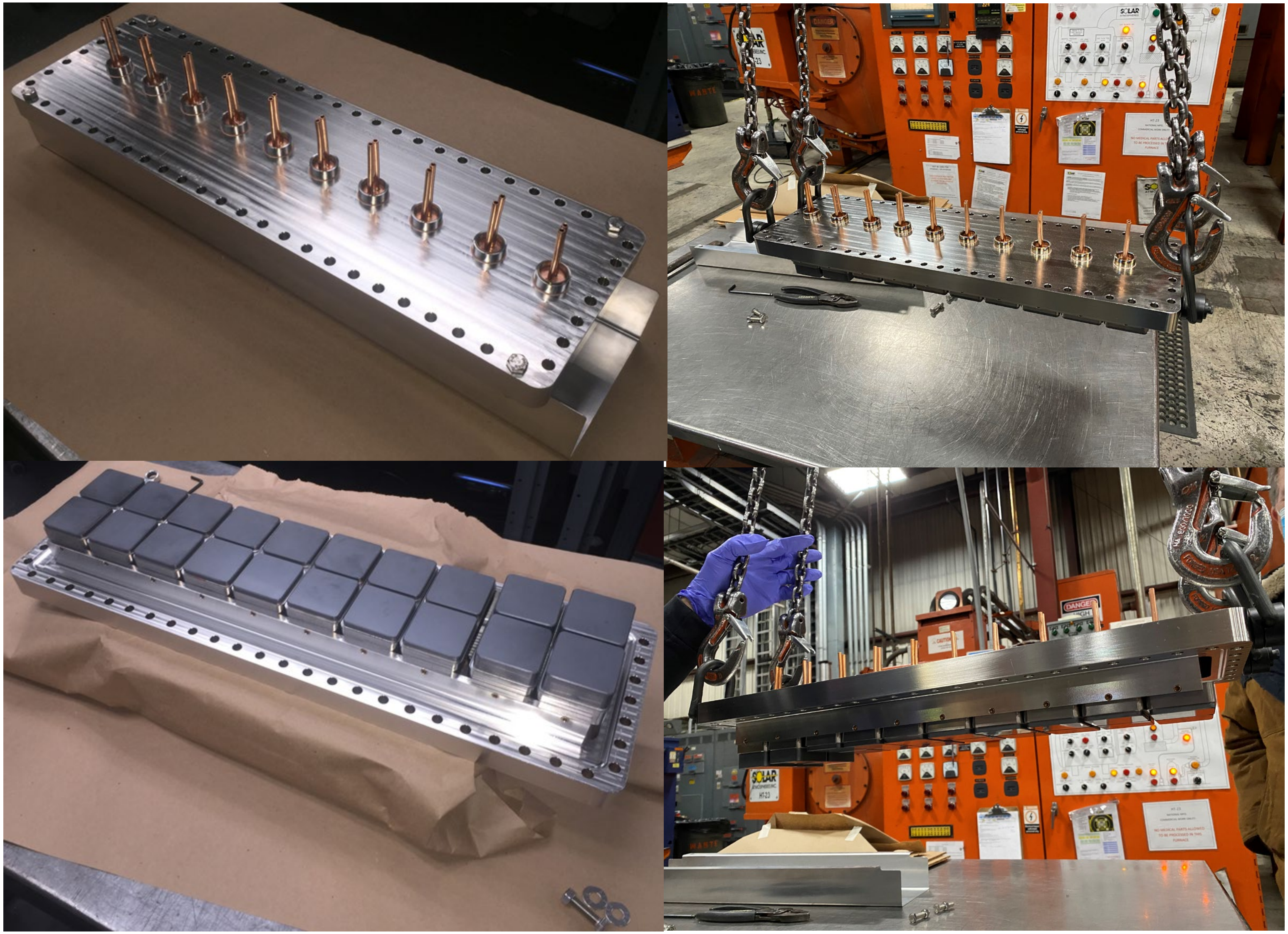


Backer/Cooling Tube Assemblies (without SiC tiles)

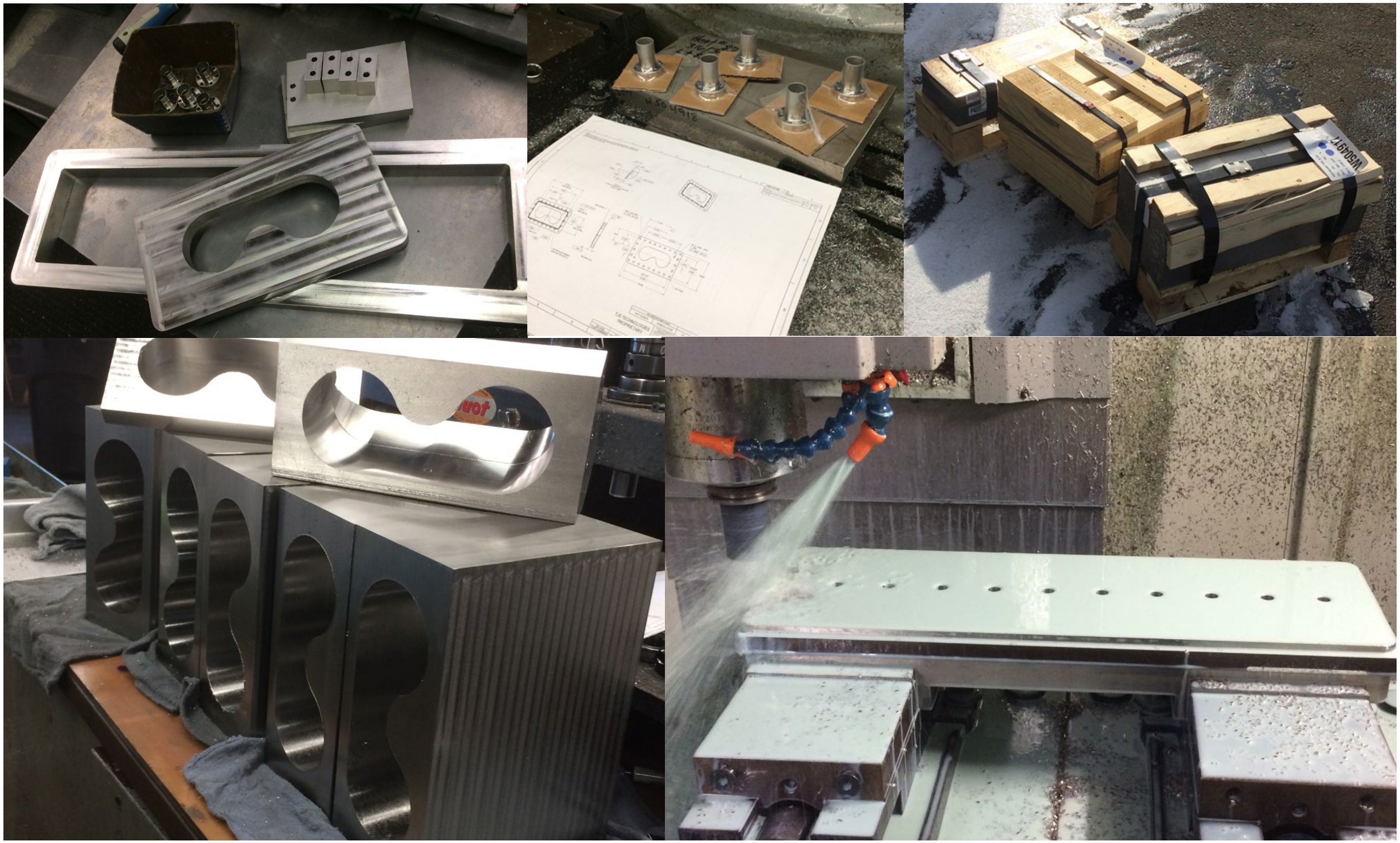
SiC tiles

Backer-Tile Assemblies shown after joining

Assembled Tile/Backer Flange

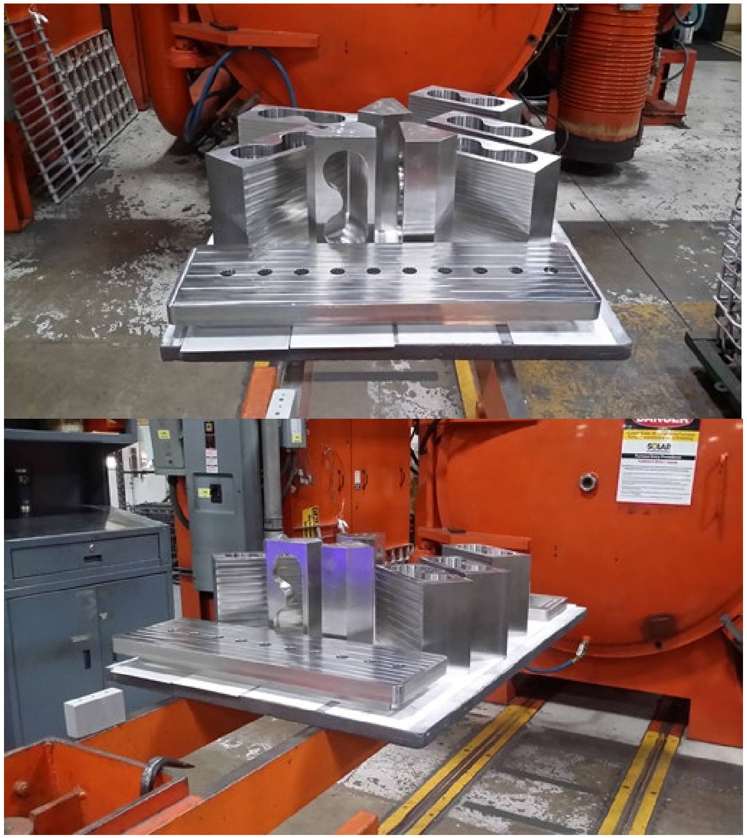


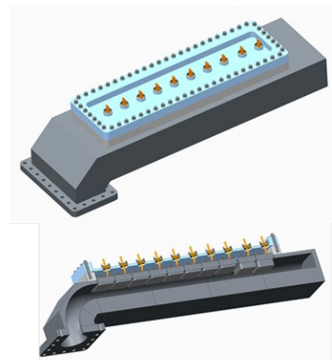
Machining of Waveguide Housing



Machining of Waveguide Housing Parts

Fabrication of Waveguide HOM Absorber





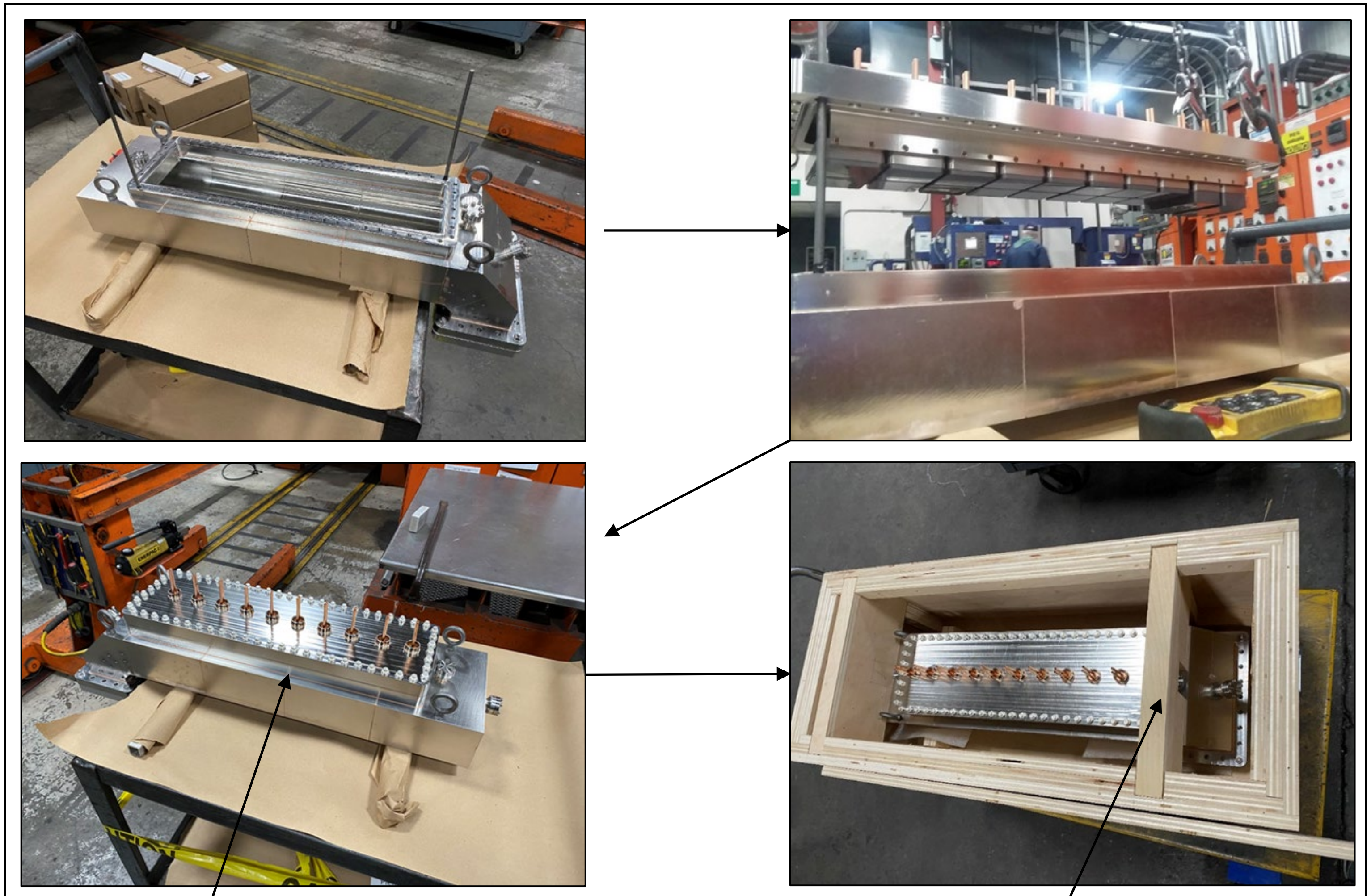
Waveguide parts after heat treat (annealing). Prior to final machining.

Parts stacked with braze alloy - thermocouples applied, ready for intermediate braze step

Waveguide HOM Absorber Housing

Tile/Backer Flange Assembly joins to flange

First Waveguide HOM Prototype



Lowering tile/backer flange assembly into housing

Bolt Flange assembly to housing

Inserting and restraining in crate

First Beamline HOM Prototype

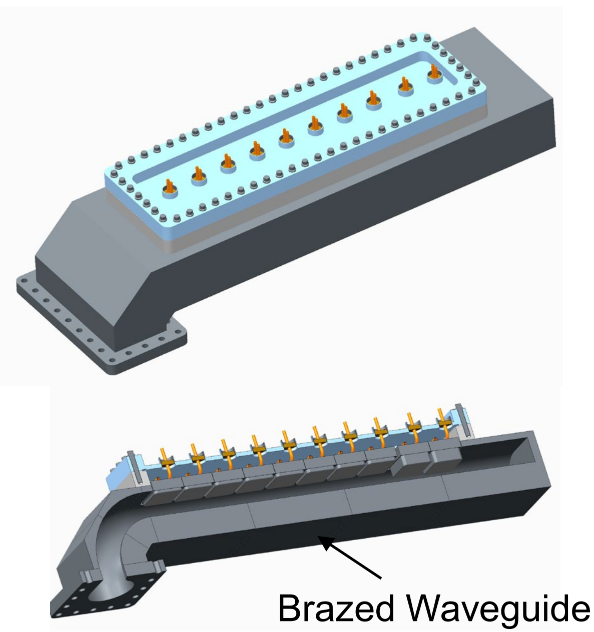
Partially Assembled

Fully Assembled

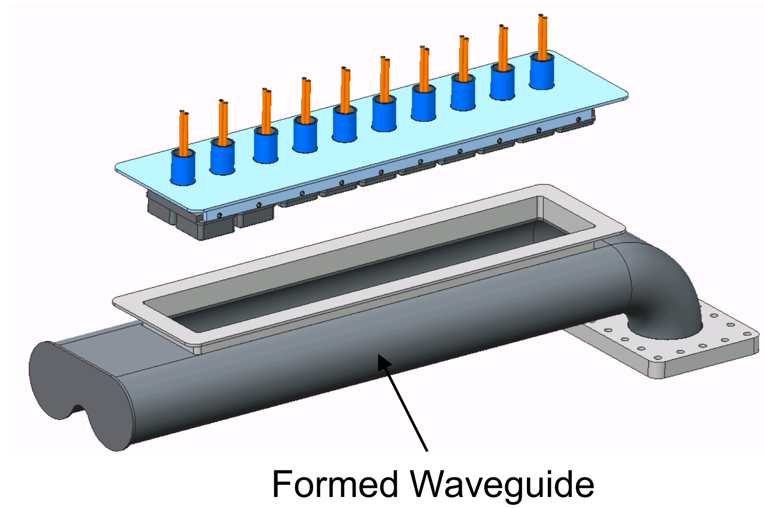
Lowering into crate

Used BNL design for thickness and depth of SiC and HOM diameter, direct replacement in their test set-up

Phase IIA Low Weight Waveguide Housing

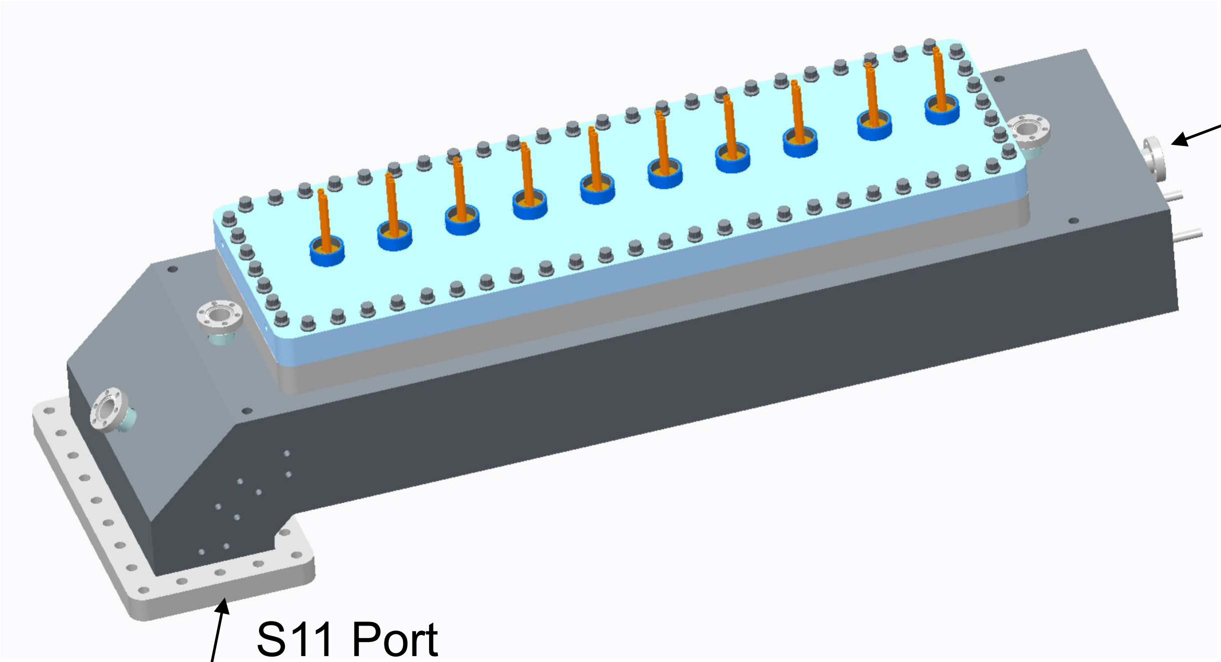


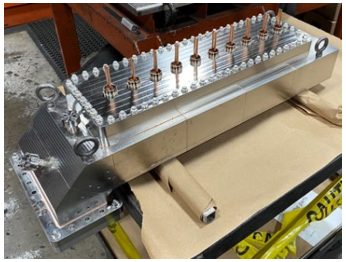
First Prototype Assembly
217.4 LBS



Low Weight Concept
59.3 LBS

Phase IIA Waveguide HOM RF Sweep Test





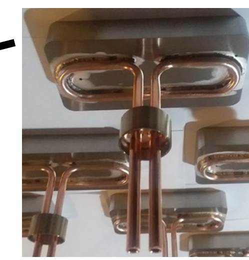
Add flange with port and antenna
Launch modes up to 3.0 GHz through S11 port
Record S11 for each mode with S21 shorted
If needed change antenna length for range of frequencies
Add S21 antenna
Launch modes up to 3.0 GHz through S11 port
Record S21 for each mode

Phase IIA Core RF Absorption Test Set-up

IR camera

Grid

Tile/backer assembly



Measure
Forward Power
Reflected Power
Tile Temperature

Phase IIA Crab Cavity

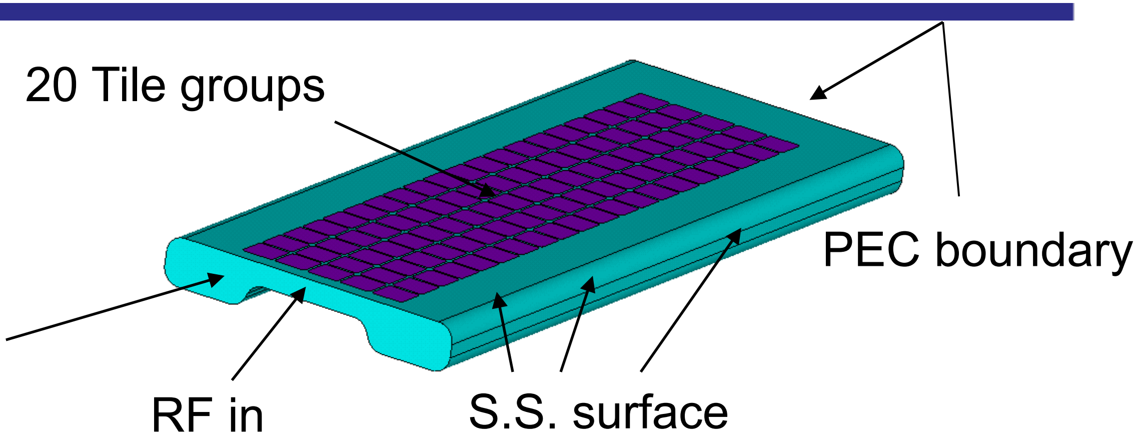
Driven Model

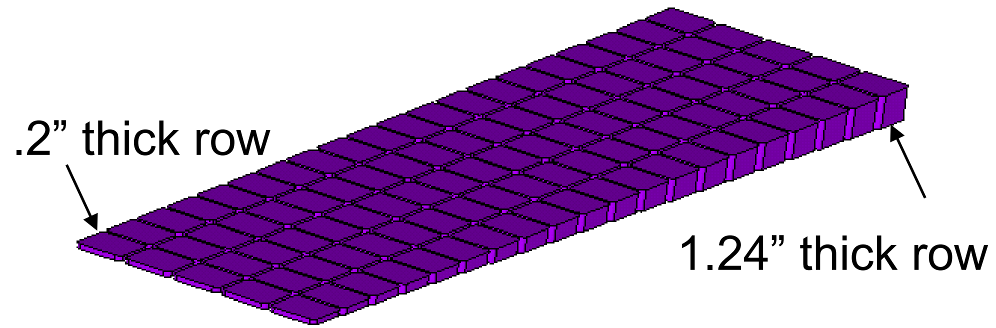
Input Excitation Port
Accepts 300 MHz and greater

Frequency Dependent
permittivity and Loss tangent

Surface Losses assuming
Stainless Steel

Output
S11- Can add HOM power for
each frequency

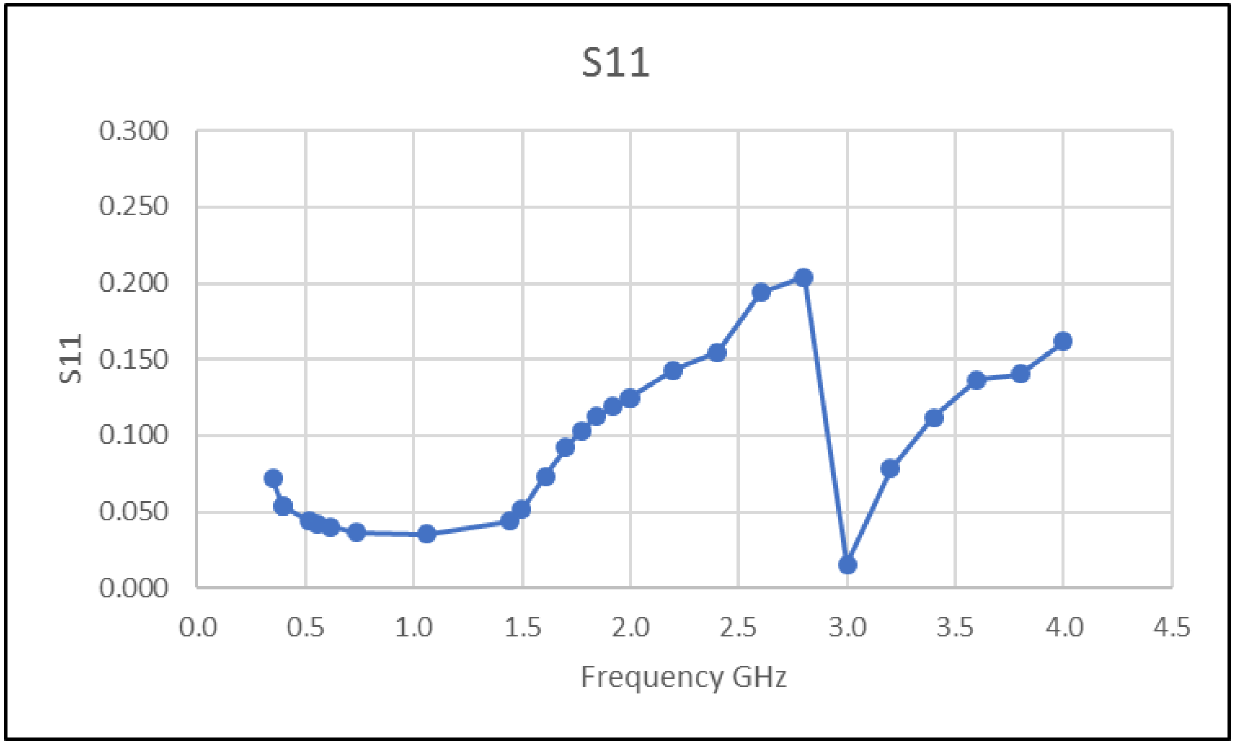




Tile groups with varying thickness

Phase IIA

S11 for 30 Rows



S11 of .1 = -20 dB
S11 of .2 = -14 dB

S11 at 397.6 MHz = .0538 = -25 dB

SBIR Summary

- Fabricated waveguide and Beamline HOM Absorbers
- Evaluating HOM absorber for Crab Cavity
  - HOM freq to absorb > 300 MHz
    - Crab Cavity design not fully developed - no Freq-Power table
- Developing Lightweight waveguide housing design
  - For present waveguide design or Crab Cavity
- Beampipe absorber diameter can be accommodated by varying number of cores circumferentially
- Using HOM core can develop many geometries to accomplish HOM absorption
- Thank You
  - Michelle, BNL, JLAB, DOE